

AN EXPERIMENTAL AND CLINICAL STUDY OF AIR-EMBOLISM.

(Concluded from page 147.)

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PROPHYLACTIC TREATMENT OF AIR-EMBOLISM.

AS clinical experience and experimental research have shown that the admission of air into veins may result and often has terminated in death, it is the duty of the surgeon, in extirpating tumors which are in close proximity to the large veins within the area of the "danger zone," to resort to measures which will prevent the ingress of air, in case a vein is accidentally wounded.

The following precautionary means deserve consideration: 1, position; 2, compression; 3, ligature; 4, aseptic tampon.

1. *Position.* Regular respiratory movements of the chest are necessary to maintain the equilibrium between the arterial and venous circulation, and should always be secured in operating in close proximity to veins at the base of the neck, as during a sudden deep inspiration the direct aspiratory effect of respiration in the veins extends to some distance, thus constituting the direct cause of entrance of air into an open vein.

Before anæsthetics were used, Poiseuille advised that the patient should be instructed not to make any deep inspiratory movements during the operation. At the present time the same object is better obtained by keeping the patient thoroughly and continuously under the influence of the anæsthetic.

Gerdy aimed to prevent the aspiratory effect of respiration by recommending compression of the thorax, but the advice is more useful in theory than in practice, as suspension of the thoracic movements for any length of time would necessarily interfere with respiration, and cause death by asphyxia.

The venous circulation is greatly influenced by position. In the elevated position the blood gravitates towards the heart, and the veins are emptied. If in this position a vein is wounded and the walls of the vessel do not collapse on account of some anatomical peculiarities, or from rigidity of the vein wall itself, a vacuum is formed, and air enters. The entrance of air into a vein distended with blood is a physical impossibility. In reading the clinical histories of cases where air entered veins during operations, we are met by the fact, that in almost all of the cases the wounding of the vein was not followed by any considerable loss of blood, and we are usually told that the air entered almost immediately after the vessel was injured, which would indicate that the vein was empty, or nearly so, at the time it was wounded. In a number of cases the bloodless condition of the vein attracted the attention of the operator, and is particularly emphasized in the description of the cases. As long as the interior of a vein and the lumen of a wound in its walls are occupied by a continuous stream of blood, there is no danger that air will be admitted. Statistics tend to show that the accidental admission of air into veins was more frequent before anæsthetics were used—a fact which we can only explain by assuming that the patients were then usually placed in a sitting or semi-recumbent position during the operation, positions favorable to the return of venous blood from the cervical region. On the other hand, the safe administration of an anæsthetic necessitates the supine position in which the veins of the neck become distended with blood. In the former instance, the return of venous blood in the vessels of the upper portion of the body was favored by the elevated position, and the vacuity thus produced in the veins constituted the most important and potent factor in determining the entrance of air. In the supine position, the veins of the neck are never empty; and to effect entrance of air, the exciting cause must operate with increased intensity. On this account the supine or dependent position of the region of the body to be operated upon recommends itself as the simplest prophylactic measure against the accidental entrance of air into wounded veins. This position increases the risk of hemorrhage from the injured vein, but this accident in its immediate effects is less disastrous

to the patient and more readily under the control of the surgeon than air-embolism.

2. *Compression.* Compression of a vein between the seat of operation and the heart, for the purpose of guarding against the entrance of air, may be divided into intermediate and direct. Intermediate compression is only applicable in cases where the external jugular vein is in danger of being wounded. If the tumor to be extirpated is not located too low in the region of the neck, uninterrupted digital compression of the external jugular vein just above the clavicle can be relied upon in preventing entrance of air through this vessel. The internal jugular and axillary veins are so deeply situated that immediate digital compression cannot be relied upon in the prevention of air-embolism, consequently it becomes necessary to resort to direct compression whenever it is desirable to guard against this accident. Warren recommended that in the extirpation of tumors which are in close proximity to the large veins of the neck and axilla, the separation of the pedicle should be reserved until the last, in order to enable the operator to compress the vein between the seat of operation and the heart more effectually, should the vessel be injured during the operation. Langenbeck advised that the vein on the distal and proximal sides of the tumor should be exposed to sight as a preliminary measure, before attempting the removal of the tumor, with the view to facilitate direct compression, in case the vessel should be opened during the dissection. The adoption of this precaution would successfully prevent a second ingress of air, but would not protect the patient against the dangers arising from the first dose. Permanent central compression augments the danger of wounding the vein, from the turgidity of the vessel which it produces, while distal compression would be attended by the same risk, only in an opposite way, by rendering the vessel empty, and consequently more difficult of recognition. If the attachments of the tumor to the vein are of such a nature that they can be separated without great danger of injuring the vessel, then the vein should be isolated on the proximal side, and the vessel compressed with a hæmostatic forceps, which will afford greater safety than digital compression. At the same time, the field

of operation is not obscured and narrowed by the fingers and hand of the assistant—an item of great importance in operating in the regions of the neck or axillary space. Injury of the vein in such instances will be promptly announced by hemorrhage from the distal portion, but the entrance of air into the right ventricle is made impossible by the prophylactic compression of the vessel between the seat of operation and the heart. Should the vein be wounded, any further ill effects arising from the accident can be prevented by applying a lateral ligature, or tying both ends of the vein, according to the size of the wound, before removing the compressing forceps. In all operations, where any of the large veins are in danger of being wounded, the position of the parts should be such as to retain as nearly as possible their normal anatomical relation. The operator should make haste slowly, and identify every structure before using cutting instruments. In extirpating tumors that are deeply situated, the external incision should always be large, so as to afford free access to the base or deepest portion of the growth to be removed. A pair of Billroth's retractors will do good service during the deep dissection. Hemorrhage must be carefully arrested as it occurs, in order to enable the surgeon to see what he is doing. Isolation of the vein from the tumor must be accomplished by the use of blunt instruments, and all former attachments should be carefully examined and identified before using the knife or scissors. As it is usually impossible, or, at any rate, impracticable to find the vein in the tumor or its immediate vicinity, the rule should always be followed to expose the vessel for some distance from the tumor on the proximate side, and then follow it by carefully separating the attached tissues by means of blunt instruments. Under antiseptic precautions the jugular vein can be isolated for a great distance, without fear of compromising the vitality of its lumen or causing thrombosis. When a tumor is attached to the jugular vein, it is a dangerous practice to make traction on the tumor for the purpose of facilitating the deep dissection, as this procedure will disturb the normal anatomical relations of the vessel, and expose it to greater risk of being wounded. Free access to the base of the tumor must be secured without displacing the subjacent vein. As

soon as the tumor has been isolated from the surrounding tissues, a thorough examination should be made of the extent of its base, and its relations to the subjacent vein, before proceeding any further with the dissection. If the conclusion is reached that the vein is so intimately connected with the base of the tumor that it is in great danger of being injured during the further progress of the extirpation, it becomes necessary to resort to direct compression of the distal and proximal portion of the vein. By isolating and compressing the vein on each side of the tumor, both excessive turgidity and emptiness of the intervening portion of the vein are avoided. The amount of blood in the vein between the two points of compression can be regulated, and only a sufficient quantity is allowed to remain to indicate the exact location of the vessel. Compression is again made with hæmostatic forceps. After the complete removal of the tumor, the forceps on the distal side of the vein is removed first, in order to test the integrity of the vessel, and with a view to prevent any possibility of the entrance of air. If no hemorrhage takes place, we may be satisfied that the vein has not been injured, and the remaining pair of forceps can be safely removed. In such cases the exposed portion of the vein should always be covered with the adjacent tissues by deep sutures, *en étages* of catgut, before closing the wound. If the vein has been wounded, a lateral ligature is applied, or both ends are ligated after complete division of the vessel, before the forceps between the vein wound and the heart is removed. By following this plan we accomplish the following objects: 1. Hemorrhage from the injured vein is slight, and perfectly under the control of the surgeon. 2. Absolute security against the entrance of air. 3. A more thorough removal of the tumor.

3. *Ligation.* In all cases where a large vein passes through the substance of the tumor, and where isolation of the vessel appears inexpedient or impossible, double ligation recommends itself as the safest prophylactic measure against hemorrhage and air-embolism. As soon as the base of the tumor is reached, the vein is exposed on each side and tied with a catgut, and the intervening portion is extirpated with the tumor. By adopting this plan we secure for the patient absolute protection

against hemorrhage and air-embolism. Adequate collateral circulation is established in a short time, so that ligation or excision of the internal jugular or axillary veins can be done under antiseptic precautions, without danger of causing serious disturbance of the cerebral circulation in the former, or gangrene of the arm in the latter instance. Isolation and ligation of the vein on the proximal side of the tumor should always be resorted to, when injury to the vein is unavoidable. In case the prophylactic ligation of the vein on the distal side of the tumor is rendered difficult or impossible by existing circumstances, the following course can be pursued: After ligation of the vein on the proximal side of the tumor, a hæmostatic forceps is applied a little distance from the ligature on the side of the tumor, and the vessel is divided between the forceps and the ligature. The ligature prevents the entrance of air, and the forceps serves the purpose of a temporary hæmostatic agent during the extirpation of the tumor. The base of the tumor with the vein is detached, when the vessel on the distal side of the tumor is sought for and tied, and the remaining attachments of the tumor, including the vein, are cut. This plan affords protection against the entrance of air, but during the separation the tumor troublesome hemorrhage may occur from accidental wounds of the distal portion of the vein, which, however, can be readily controlled by compression with hæmostatic forceps until the vessel is permanently secured on the distal side of the tumor.

4. *Aseptic Tampon.* If a large vein has been wounded, which, from its location, is inaccessible to the ligature, permanent compression with a graduated aseptic tampon will arrest the hemorrhage and prevent further ingress of air.

OPERATIVE TREATMENT OF AIR-EMBOLISM.

Considering the infrequency of air-embolism, as compared with the number of vein wounds, it is not surprising to find that, as a rule, surgical writers have little, if anything, to say on the subject of the prevention and treatment of air-embolism. It must be apparent to all that, in following the rules laid down when we considered the prophylactic treatment, the accidental

introduction of air into veins is prevented almost to a certainty. At the same time, they will also furnish a safe guide in the prevention and management of venous hemorrhage, when operating within the area of the "danger zone." If the preventive treatment is carefully carried out, air-embolism will become one of the rarest accidents in surgery.

As even with the greatest care an accident of this kind might happen, it is necessary to allude to the operative treatment of air-embolism. The occurrence of the accident is sometimes announced by an audible hissing or sucking sound, and is always followed almost instantly by a well-marked train of distressing symptoms, which are directly referable to a mechanical obstruction to the circulation in the right side of the heart and the pulmonary artery. The treatment must depend on the quantity of air which has entered, and the severity of the symptoms produced by it. The therapeutic measures should be aimed towards meeting the following indications: 1. Prevention of further ingress of air. 2. Administration of cardiac stimulants. 3. Venesection. 4. Aspiration of air from the right side of the heart.

1. When air has entered through a gaping wound in a vein during inspiration, there is great danger that the same occurrence will repeat itself during successive respiratory movements of the chest; hence, the first object of treatment consists in closing the wound in the vein. This is most quickly done by digital compression, which is continued until the vein has been rendered impermeable by ligature or permanent compression. If the symptoms are urgent, no time should be lost in securing the vessel, until the patient has rallied from the immediate effects of the air embolism. It is also necessary to postpone the permanent closure of the vein until the time has elapsed for any indications to arise which would call for venesection, or operative removal of the air from the right side of the heart, as in such cases it may become necessary to utilize the wounded vein as a route for the introduction of a catheter into the heart. When the time has arrived for closing the vein, the finger should not be removed suddenly from the vessel, for fear of causing a repetition of the accident; it should remain *in situ* until the vessel can be compressed on the prox-

imal side of the vein wound by an assistant. The exact location of the wound will now be probably indicated by escape of blood from the distal end of the vein, when the vessel can be seized with forceps, and, after its isolation, a double ligature is applied. If it is found impossible to ligate the vein, then the vessel is compressed in the wound by means of a graduated aseptic tampon, retained in place by uninterrupted pressure until definitive closure has taken place.

2. The heart's action must be supported by position and by the use of cardiac stimulants, which are best administered subcutaneously and by inhalation. The patient must be placed in the supine position, with a view of guarding as much as possible against the occurrence of cerebral anæmia, as well as to lessen the intravascular pressure to a minimum. If the quantity of air admitted is not sufficient to produce instant death by paralysis of the right side of the heart in the diastole, the symptoms which follow always point towards an embarrassment of the circulation in the right side of the heart and the pulmonary artery, which are always accompanied by dyspnœa, and combined with evidences indicating the existence of acute cerebral ischæmia. If death does not take place within a few minutes from obstruction to the circulation through the pulmonary artery, by the presence of air in that vessel, then the contractions of the right ventricle will force at least a part of the air through the pulmonary capillaries into the general circulation, thus preventing death by asphyxia. As soon as the air-embolism of the pulmonary artery has been relieved, the most urgent symptoms subside, as the air-emboli in the arterial system are distributed over a larger area, and consequently produce an embolism of lesser extent and gravity in more distant and less essential organs. The safety of the patient depends on the capacity of the right ventricle to force the air through the pulmonary into the general circulation—in other words, upon the time which is required in removing the emboli from the pulmonary artery into the systemic circulation.

Nitrite of amyl, from its stimulating properties upon the heart, and from the rapidity of its action, would recommend itself, in the form of inhalation, as the most efficient drug in preventing threatened syncope. The temporary dilation of the

small blood-vessels would tend to produce, at least for a short time, a diminution of the intravascular pressure. Hypodermatic injections of camphor and alcohol, although slower in their action, would also assist in antagonizing the deleterious effect of over-distension of the right ventricle by the air-embolus. In all my experiments where electricity was used, it had no effect whatever upon the heart, even when applied directly to the organ; hence, it would be of no use to resort to this agent for the purpose of sustaining or re-establishing the movements of this organ in serious cases of air-embolism.

3. In all post-mortem examinations, after sudden death from air-embolism, two constant pathological conditions are always found present: 1. A comparatively empty state in the left side of the heart and throughout the entire arterial system. 2. Distention of the right ventricle, and intense engorgement of the whole venous system. Both of these conditions are, of course, due to the presence of air in the ultimate branches of the pulmonary artery, which prevents the free transit of the venous blood through the pulmonary capillaries into the left side of the heart. As a direct result of these conditions, we have a diminution of the intravascular pressure in the left side of the heart and arteries, and a corresponding increase in the right side of the heart and the veins. The immediate and greatest danger arises from an accumulation of air and blood in the right side of the heart to such an extent as will arrest the ventricular contractions by over-distension before the equilibrium between the arterial and venous circulation can be restored by the removal of the air-emboli from the pulmonary artery into the general circulation. Even the most extreme antagonists to the lancet must acknowledge the benefit which follows its use in similar conditions of the circulation caused by other pathological conditions. In severe cases of pneumonia, where the circulation has been so much obstructed that death is threatened by venous engorgement and over-distension of the right ventricle, the free use of the lancet is the safest and most efficient means in equalizing the circulation, as, by the abstraction of blood from one of the veins, the intravascular pressure in the veins and right side of the heart is diminished in the promptest and most direct manner.

As the adventitious air in the pulmonary capillaries can and will be forced into the general circulation by the contractions of the right ventricle, and as the urgent symptoms will subside after this has taken place, it is of paramount importance to gain time by protecting the right ventricle against an undue amount of additional labor. Among the indirect remedies to accomplish this object, venesection deserves the first place. I could refer to a number of the experiments where copious bleeding from the distal portion of the open vein was promptly followed by improvement in all the symptoms. Vulpian asserted that, after insufflation of air into veins, the contractions of the heart were restored after the organ had ceased pulsating, by the abstraction of blood from the sinuses of the brain and the veins of the neck. I have never succeeded in restoring the action of the heart, after its pulsations had ceased completely, by any kind of treatment; but, when the contractions have become imperfect from this cause, I know that removal of the cause of over-distension will restore the force and efficiency of the contractions. H. Fischer (*Ueber die Gefahren des Luftintritts in die Venen*, p. 17) sarcastically alludes to this valuable agent in the treatment of air-embolism as a remedy from which only homœopaths would expect to derive any benefit. An expression of this kind, concerning such a valuable remedy, and in this particular connection, must be looked upon as unscientific and contrary to well established clinical and pathological facts. I must, therefore, insist that venesection from the distal end of the wounded vein will prove beneficial in all cases of air-embolism where venous engorgement and over-distension of the right ventricle constitute elements of imminent danger. If practicable, the bleeding should always be done from the distal end of the wounded vein, while the proximal end is compressed or ligated. The advantages of doing so are obvious for the following reasons:

(a) The abstraction of blood is accomplished in the shortest possible space of time.

(b) The blood escapes in a large stream from a capacious vessel.

(c) No additional instruments are required, and the infliction of another wound is obviated.

4. Clinical experience and experimental research teach us, that when a certain amount of air enters the right side of the heart, death invariably takes place in a very short time, and cannot be prevented by any of the indirect methods of treatment. It seemed to me that in such cases it would be legitimate and proper for the surgeon to resort to some procedure by which the air could be removed directly from the heart. To accomplish this object, Fischer recommends that forcible expiratory movements should be excited by inducing coughing, sneezing, or vomiting, with a view that during the forcible compression of the thorax the aspirated air would be forced out through the wound in the vein. Against this advice the following objections may be entered: 1. The difficulty or impossibility of exciting coughing, sneezing, vomiting or any other act on the part of the patient, when in a condition of collapse. 2. If during the forcible compression of the chest the air is forced backwards, it will be just as likely to pass into other veins than the one through which it entered. 3. The difficulty of preventing the admission of more air during the forcible inspiration following the forcible expiration. 4. During prolonged forcible expiration the intra-vascular pressure in the veins and right side of the heart is greatly increased, thus constituting an additional source of immediate danger. 5. Forcible expiratory movements of the thorax, by compressing the heart, will be more likely to force the air onward with the venous current into the pulmonary artery, where it will do the most harm by causing asphyxia from a sudden and extensive air-embolism in that vessel.

The only direct means of removing air from the heart consists in puncture of the right ventricle and catheterization of the right auricle combined with aspiration. The experiments made by myself in this direction have demonstrated that puncture of the right ventricle with an aseptic needle two millimetres in diameter is in itself a harmless procedure. When we remember that in the human subject the heart has often been the seat of more extensive injury without any immediate or remote ill effects, we must abandon the idea that slight injuries of this organ are necessarily fatal. Small aseptic wounds of the heart heal rapidly and in the same manner as in

any other organ of the body. The hearts, which I show you, were removed from dogs a few days to three weeks after puncture, and not in a single specimen are we able to detect any evidences of organic changes either in the substance of the organ or its serous membranes. In most of the specimens the point of puncture is marked by a minute cicatrix visible upon the surface of the visceral pericardium. In penetrating wounds of the heart, hemorrhage into the pericardium and compression of the heart from this cause are to be feared, and constitute the only source of immediate danger. There is no plausible reason why, in the human subject, an oblique puncture of the right ventricle should be followed by more hemorrhage than in animals, and consequently I have no hesitation in recommending puncture and aspiration of the heart as a justifiable procedure in cases of air-embolism which would otherwise necessarily prove fatal. The question naturally arises: What symptoms indicate a resort to puncture and aspiration of the right ventricle? Two different conditions, as far as time and symptoms are concerned, may call for this operation. The puncture should be made as soon as possible after the entrance of air in the event that the primary effect of the heart embolus has produced sudden over-distension and paralysis of the right ventricle, an occurrence which would be indicated by immediate collapse and partial or complete suspension of the heart's action. In such a case, the direct withdrawal of air from the right ventricle as soon as possible after its entrance affords the only possible hope of restoring the pulsations of the heart by removing the cause of the mechanical over-distension. In the second class of cases the patient has collapsed, but the heart has withstood the primary effect of the aspirated air. The heart's action is rapid and tumultuous, perhaps at times intermittent. The ear applied over the cardiac region detects distinct churning sounds. Respirations are rapid, and all symptoms point towards imperfect circulation and æration of the blood, as expressed by the pallid face and blue lips. Some of the air has passed from the right side of the heart into the pulmonary artery, and, from the obstruction of the circulation through this vessel, the right ventricle becomes more and more distended, the contractions therefore are less perfect

and more frequent. At this stage of things puncture and aspiration of the right ventricle will overcome the most urgent symptoms by the removal of air and spumous blood, and enough time may be gained for the right ventricle to force the remaining air emboli through the pulmonary capillaries into the general circulation, and the life of the patient is saved. These are the cases where puncture and aspiration of the right ventricle can be done with a fair prospect of not only relieving urgent symptoms, but of ultimate recovery. They are also more favorable from the fact that more time is afforded the surgeon in procuring and using the aspirator. The puncture should always be made in an oblique direction from below upwards, so as to make a valvular track in the heart, for the purpose of preventing hemorrhage into the pericardium, and also for giving the point of the needle a direction in which it is least likely to injure the opposite endocardial lining. The left intercostal space between the fourth and fifth ribs, about an inch and a half from the margin of the sternum, is selected as the best point for making the puncture. The needle, thoroughly disinfected, is connected with the aspirator, and, as soon as its point is buried in the tissues, a vacuum is created in the aspirator, and the needle is advanced slowly until spumous blood is felt and seen to escape, when it is firmly held in this position and the contents of the ventricle are withdrawn as quickly as possible.

My experiments have satisfied me that I generally removed the needle too soon, not having withdrawn a sufficient quantity of blood and air. In some of the experiments I followed the aspiration by blood-letting with marked benefit. Removal of the same quantity of blood directly from the right auricle would have been productive of more good, as less air would have been left in the heart. The experiments on dogs have shown that these animals will always recover if the quantity of air injected into the veins does not exceed one cubic centimetre of air to each pound of its weight. Double this quantity must be considered a fatal dose. If, therefore, we can remove by aspiration only a portion of air directly from the right ventricle, we may be able to maintain the action of the heart and respiration until the embolism of the pulmonary

artery has been relieved by the passage of air from this vessel into the general circulation. When the presence of a foreign body in any other part of the body threatens to destroy life, no surgeon would hesitate to attempt to remove it, even if the effort should be attended by an increase of the immediate risk. Air in the right side of the heart acts the part of a foreign body, and when it destroys life, it does so by causing mechanical obstruction to the circulation. The timely removal of this foreign body is the only rational treatment in all cases where simpler measures have proved inadequate in preventing a fatal termination. An aspirator, in good condition, should be on hand in every well regulated hospital, and of ready access in cases of emergency. Should air-embolism occur during an operation, the instrument might be on hand and ready for use before the heart has ceased pulsating, when prompt action on the part of the operator might obviate death in an otherwise hopeless case. The experiments on catheterization of the heart were undertaken with a view to simplify the operative removal of air from the right side of the heart.

An aseptic catheter was introduced into the wounded vein and passed into the right auricle, and, by aspiration, air and spumous blood were removed. The result showed that some of the animals were saved from impending death by this simple procedure. The great danger attending this operation consisted in the tendency of the blood to coagulate within or around the distal end of the catheter, and death from the formation of a thrombus in the large veins and right side of the heart. If the formation of a thrombus could in some way be prevented with certainty, catheterization and aspiration of the heart would recommend itself as the simplest and safest measure in the operative treatment of air-embolism.

Catheterization of the heart is not a new suggestion, as the introduction of a tube into the heart, for the same purpose, was recommended more than fifty years ago by Magendie. I should recommend the adoption of this procedure only in case when the air has entered through a wound in the internal jugular, and when the symptoms leave no doubt that death would be inevitable without direct removal of the air by aspiration. An aseptic Nélaton's catheter with an open end

should be introduced into the wound, through which the air entered, and pushed as quickly as possible as far as the auricle, when the air and spumous blood can be withdrawn by the mouth in the absence of any other means of aspiration. Admission of more air is prevented by compression of the distal end of the instrument before and between the aspirations. The whole operation must be done as quickly as possible for the purpose of preventing coagulation of the blood. For the same reason an instrument of large calibre should be used.

In presenting to you the practical outcome of my experimental work in the form of these few suggestions on the operative treatment of air-embolism, I am fully aware that, in your own minds, you have decided that my labor has been in vain, and that the means suggested do not admit of application in practice. In reply, I will say, that desperate cases call for desperate measures. When death stares us in the face we have not only a right, but it becomes our most imperative duty, to resort to any plan of treatment which holds out the slightest hope of saving the life of the patient. For myself I am fully convinced of the safety and usefulness of puncture and aspiration of the right ventricle in grave cases of air-embolism, where simpler means have proved of no avail. When no aspirator is within reach, I also believe in the propriety of catheterization and aspiration by the mouth, of the heart, as a last resort in all cases of air-embolism where death would surely take place without it. If, by the adoption of either of these methods of direct treatment of air-embolism, a single human life should be saved, I shall feel amply rewarded for the labor incurred in the preparation of this paper.

In conclusion, I beg leave to submit the following *résumé* for your further deliberation and discussion:

(1.) The presence of adventitious air in the vascular system during life gives rise to air-embolism.

(2.) Each air embolus constitutes a mechanical source of partial or complete obstruction to the flow of blood in the vessel in which it is located.

(3.) Aspiration during the inspiratory movements of the chest is the direct or exciting cause of ingress of air into a wounded vein or sinus.

(4.) Elevation of the head is the sole predisposing cause of the entrance of air in wounds of the superior longitudinal sinus.

(5.) In veins the predisposing causes consist in (a) Elevation of the part wounded. (b) Pathological or anatomical conditions which prevent collapse of the vein when it is wounded.

(6.) Insufflation of a fatal quantity of air into a vein produces death by (a) Mechanical over-distension of the right ventricle of the heart and paralysis in the diastole. (b) Asphyxia from obstruction to the pulmonary circulation consequent upon embolism of the pulmonary artery.

(7.) Insufflation of the same quantity of air into arteries is less dangerous than when introduced into veins. When death is produced in this manner it results from—

(a) Acute cerebral ischæmia.

(b) Secondary venous air-embolism.

(c) Intense collateral engorgement of the vessels of the brain and spinal cord, the manner of death being determined by the amount of air injected, and the direction in which the injection is thrown, as well as the time which has elapsed between the operation and the fatal termination.

(8.) Air injected into arteries is readily forced through the systemic capillaries into the venous circulation and right side of the heart by the powerful contractions of the left ventricle.

(9.) Air-embolism of the pulmonary artery is relieved in a comparatively short time, provided the contractions of the right ventricle continue unimpaired for a sufficient length of time to force the air through the pulmonary capillaries into the general circulation.

(10.) The prophylactic treatment consists in proximal or double compression, or ligation of the vein which is endangered by the operation.

(11.) The indirect treatment has for its objects—

(a) Prevention of admission of air.

(b) Administration by inhalation of hypodermatic injection of cardiac stimulants.

(c) Venesection.

(12.) The direct or operative treatment by—

(a) Puncture and aspiration of the right ventricle.

(b) Catheterization and aspiration of right auricle, which is proposed with a view to obviate the direct cause of death by the removal of air and spumous blood, thus relieving directly the over-distension of the right ventricle, and, at the same time, to guard against a fatal embolism of the pulmonary artery.

(13.) The results obtained by experiments on animals warrant the adoption of the operative treatment of air-embolism in practice, as a last resort, in all cases where the direct treatment has proved inadequate to meet the urgent indications.

THE FIELD AND LIMITATION OF THE OPERATIVE SURGERY OF THE HUMAN BRAIN.

[Concluded from p. 129.]

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I HAVE now with great detail discussed what I conceive to be the principles of the operative surgery of the human brain. It remains to apply these principles to the treatment of:—

- A. Cranial fractures.
- B. Intracranial hemorrhage.
- C. Intracranial suppuration.
- D. Epilepsy following cranial injury.
- E. Insanity following cranial injury.
- F. Cerebral tumor.

A. In discussing the treatment of cranial fractures, I shall ask myself four questions:

- 1. What conditions demand incision of the scalp?
- 2. What conditions render incision of the scalp unjustifiable?